Urban Scale Aerosol Dispersion Modeling

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Adaptive Urban Dispersion Modeling

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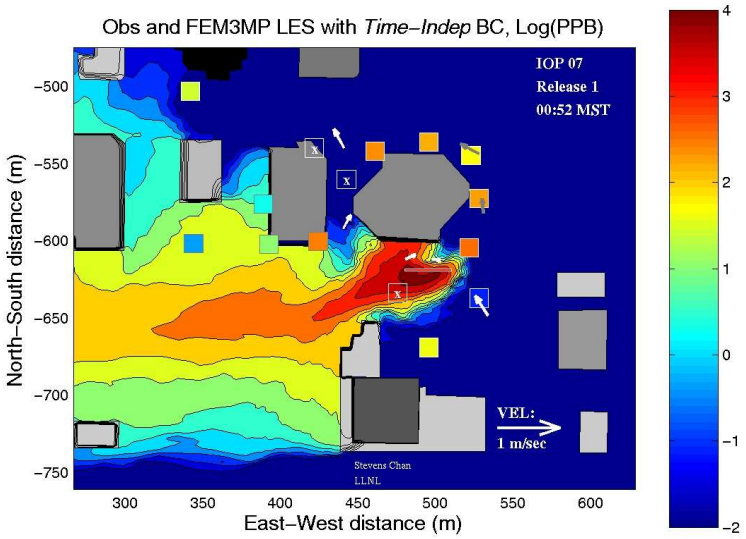
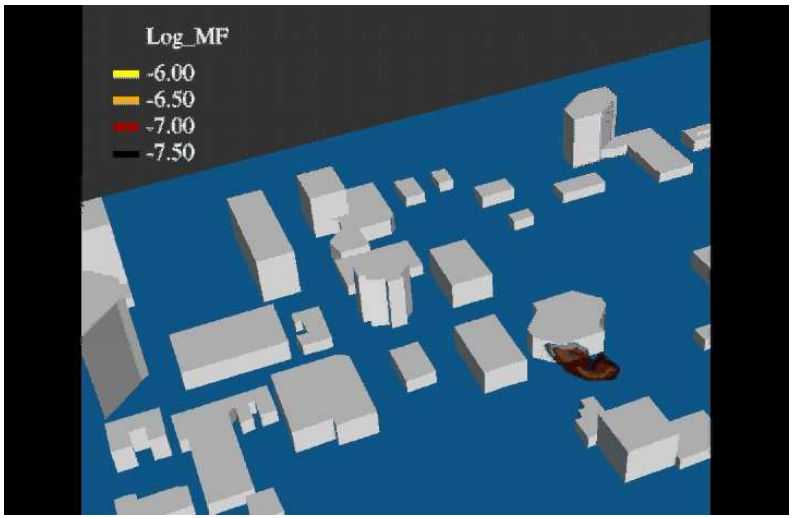
Prediction of aerosol dispersion is a critical homeland security need

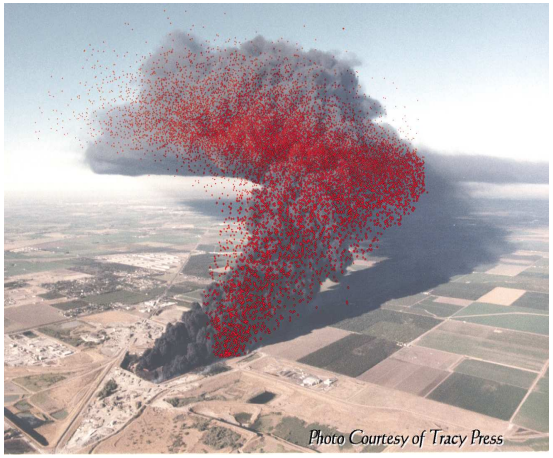
- **High fidelity models that predict the spread of airborne hazardous materials are important**
  - **Field experiments are difficult and expensive**
  - **Assist in emergency planning and response scenarios**
  - **Guide effective sensor placement**
  - **Event reconstruction (with measurements)**





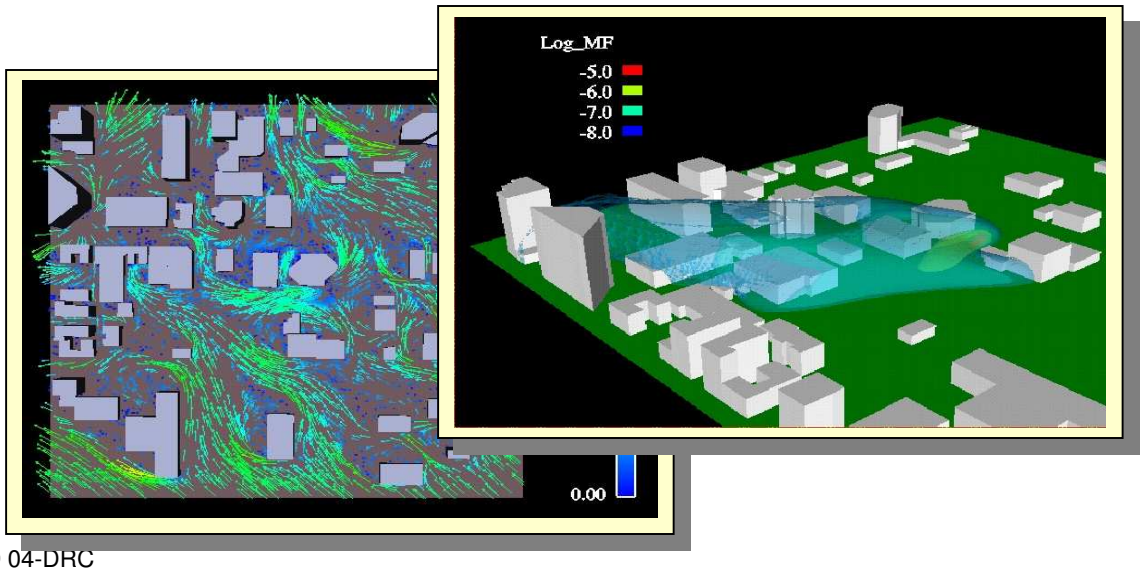
NARAC: An operational release advisory center at LLNL

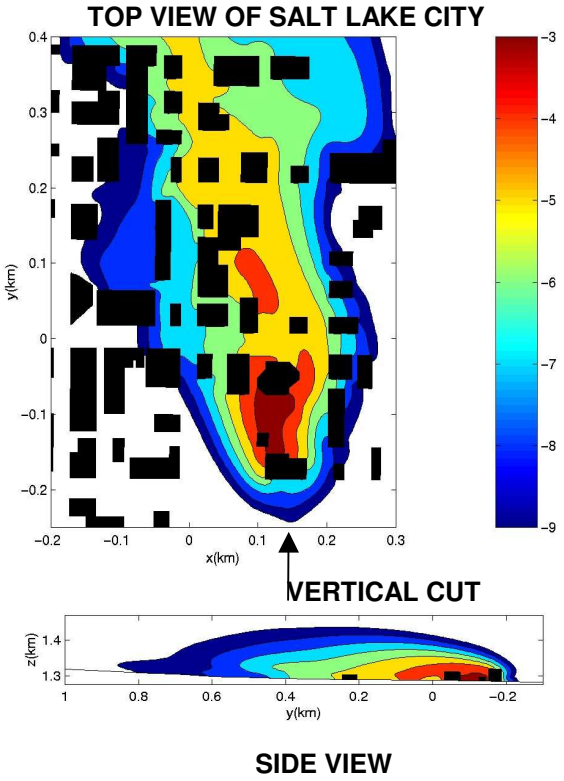
- **National Atmospheric Release Advisory Center**
  - Supports the DHS Emergency Preparedness and Response (EPR) directorate
  - Provides detailed predictions of atmospheric releases for real-time emergency response, pre-planning, and post-incident assessments
  - Incorporates hierarchy of models for different types of release events, distance scales, and response times



NARAC has models for urban dispersion simulation

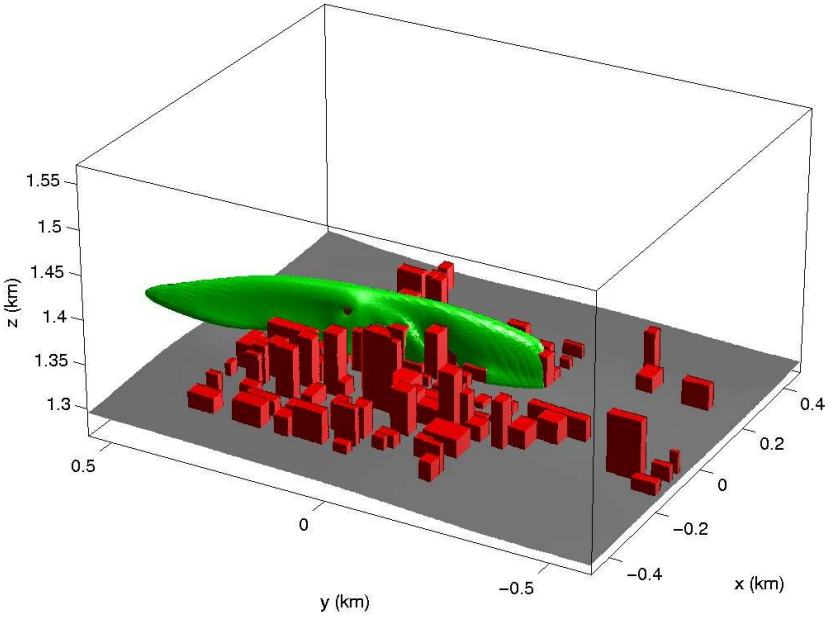
- **FEM3MP is the primary urban dispersion modeling code used in the atmospheric sciences division in NARAC**
  - **Finite element incompressible CFD**
  - **Structured mesh**
  - **LES & RANS turbulence models**
  - **Atmospheric chemistry**

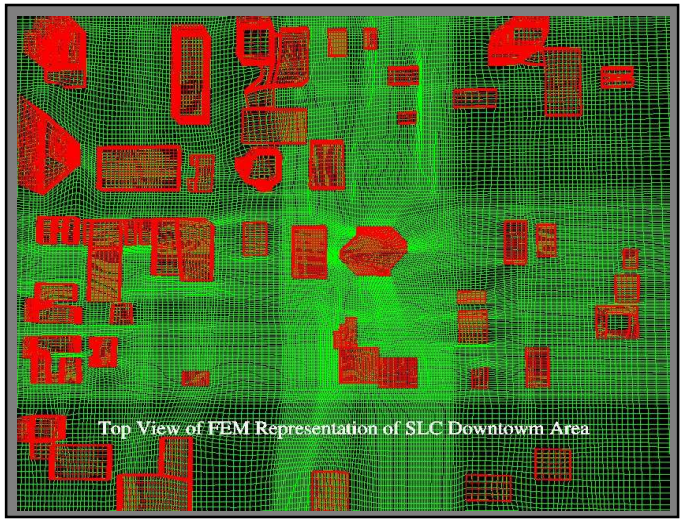




Current urban modeling capability has some limitations

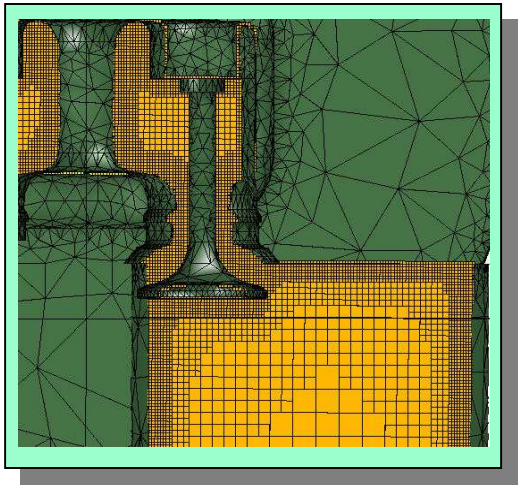
- Unable to resolve complex building geometries
- Labor-intensive grid generation
- Limited capability for fast evolving flows
- Limited range of release scenarios (e.g., moving sources)



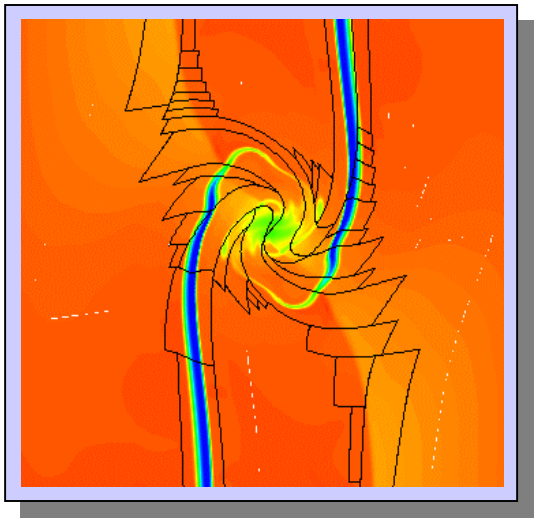


We are developing advanced meshing tools to enhance capabilities

- **Overture** project has tools for rapid geometry-to-mesh (Rapsodi)
  - Rapid construction of surface grids from CAD data
  - Interfaces to fast volume grid generator from NASA (CUBES)



- **SAMRAI** infrastructure supports parallel AMR applications
  - Data structures for flexible mesh geometry
  - Adaptive mesh refinement
  - Scalability verified on > 1K processors



Couple technologies to develop an operational tool

FEM3MP
CFD code for urban dispersion

SAMRAI
Parallel adaptive mesh support

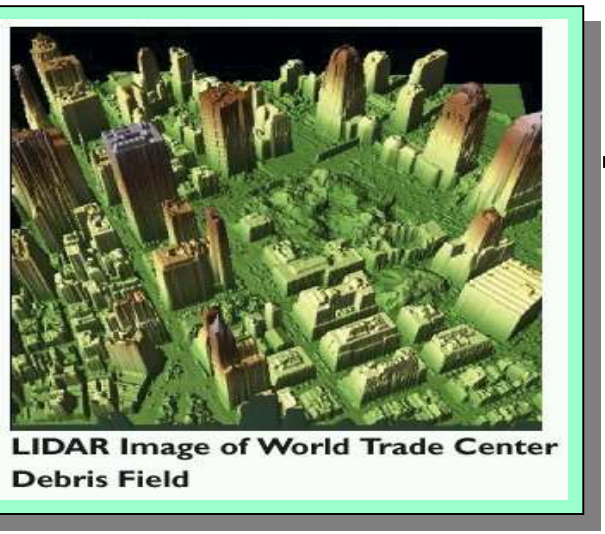
Overture
Rapid geometry to mesh capability

Next-generation Integrated Urban Dispersion Capability

- **Automatic mesh construction from building datasets.**
- **Geometrically complex buildings and cityscapes**
- **Diverse urban environments:** stadiums, arenas, subways, etc.

- **Adaptive mesh refinement for enhanced fidelity:** release points, building entrances, etc.
- **Complex release scenarios:** moving sources, etc.

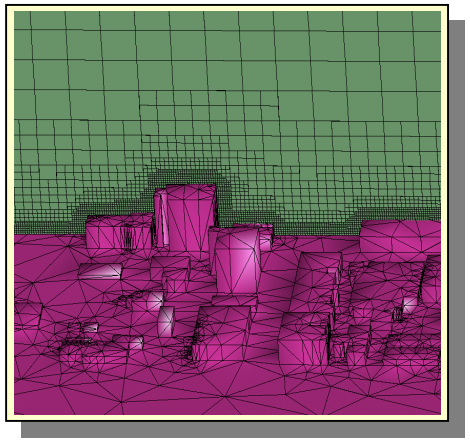
Integrated approach will enable automated geometry to CFD analysis



LIDAR Image of World Trade Center Debris Field

Overture (Rapsodi)
Surface grid generation

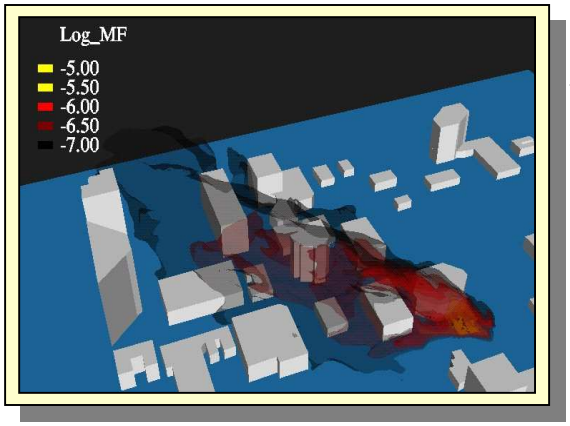
CUBES
Volume grid generation



Adaptive Cartesian grid

FEM3MP
CFD & Dispersion Models

SAMRAI
Adaptive meshing, complex geom defn



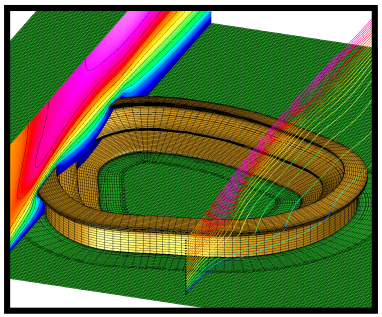
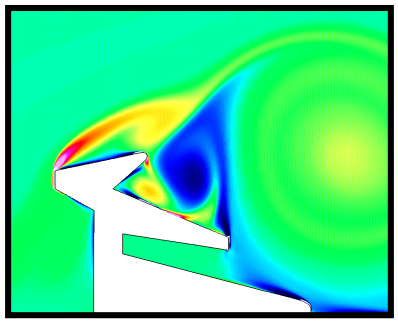
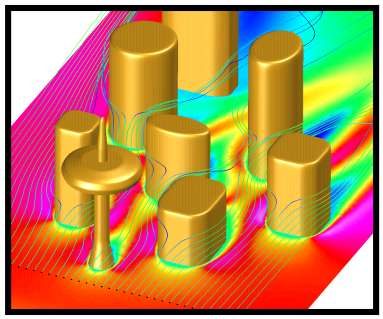
Parallel Adaptive flow solution

Links exist

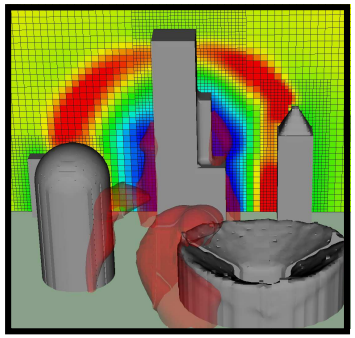
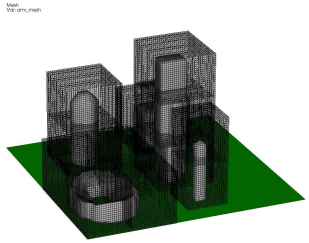
Developing links

Some demonstration calculations around complex building geometries

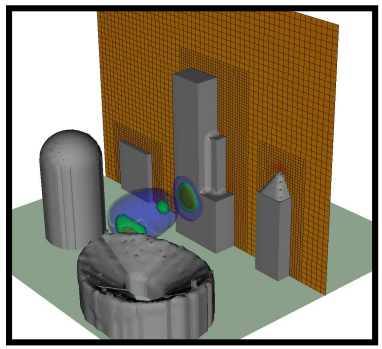
- **Flow around stadium and sample cityscape with overset grids**

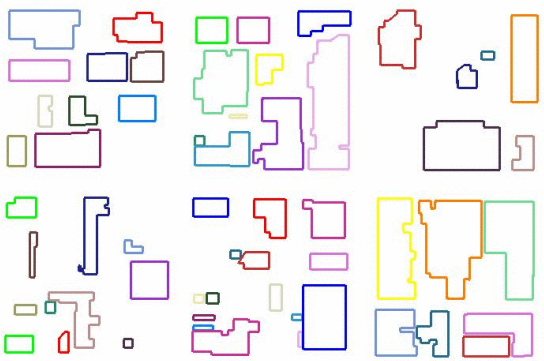
- **Adaptive flow simulation over prototype cityscape with cut-cell grids**

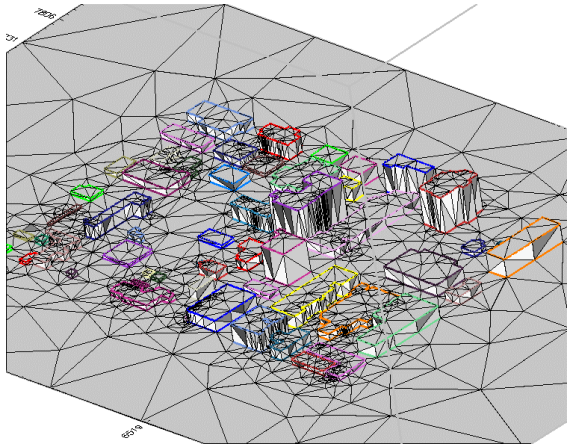
Refined region around buildings



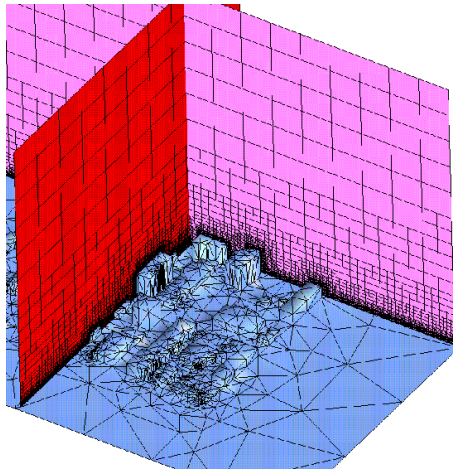
Automatic construction of grids from building datasets



Polygonal geometry data (Salt Lake City)



Surface triangulation by metro



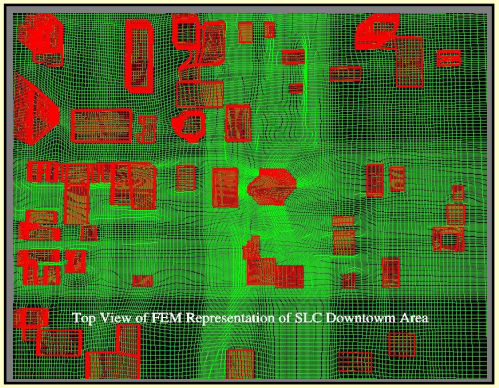
AMR volume mesh by CUBES

- "metro" reads building geometry data and generates surface triangulation and CUBES input
- Prof. Marsha Berger, NYU Courant, is a CUBES co-developer and a collaborator on this project

Grid generation time reduced from weeks to minutes

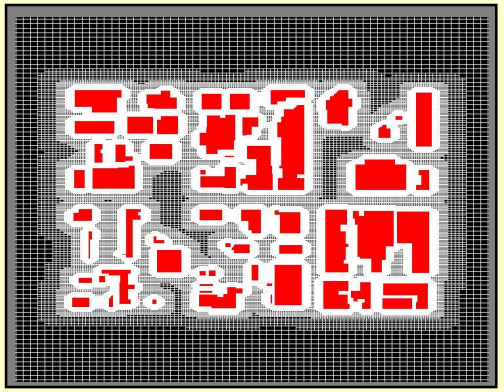
Downtown Salt Lake City gridding example

- **Structured grid constructed with existing tools required about <u>1 week</u>**



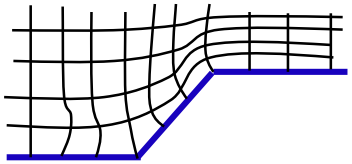
- **Adaptive cut-cell grid generated with metro + CUBES required about <u>2 minutes</u>**

1.7M gridpoints, 6 levels refinement
Surface grid – 30 sec with “metro”
Volume grid – 45 sec with “CUBES”

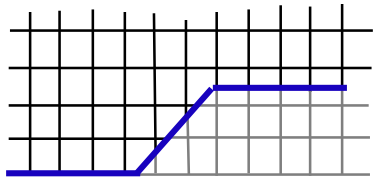


Research Issues to be addressed in 2004-2005

- **Finite element boundary representation on cut-cell grids using "fictitious domain" algorithm**



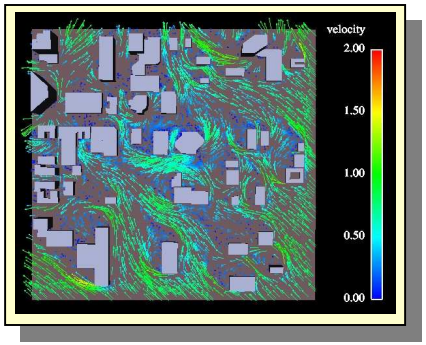
"conforming" mesh (old)



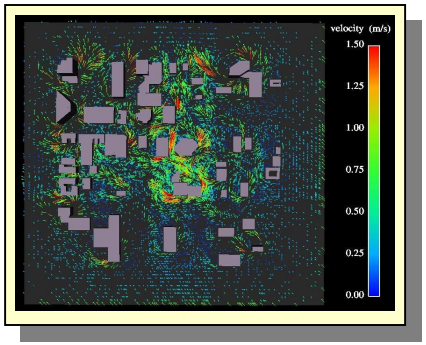
"cut-cell" mesh (new)

- **Adaptive algorithms for finite element CFD solver**
- **Turbulence models**

RANS



LES

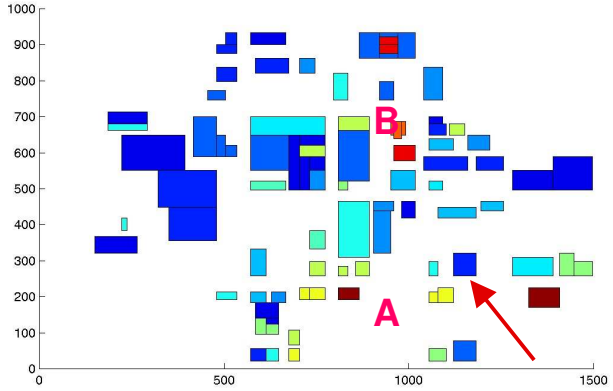


- **Building geometry information that incorporates new features (e.g. terrain)**

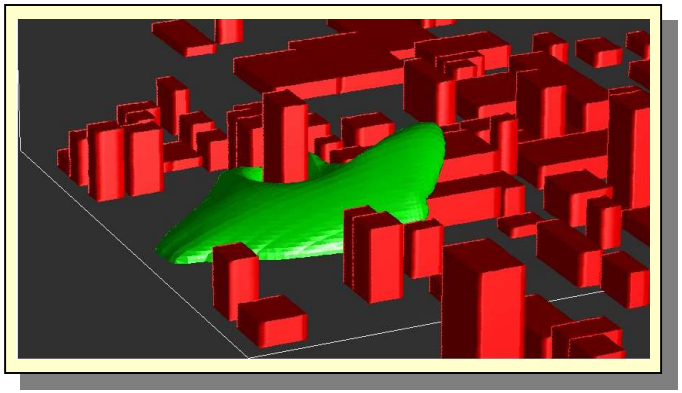
We will use experimental data to verify and validate model accuracy

- Joint-Urban 2003 in Oklahoma City
- Urban 2000 in Salt Lake City
- Wind tunnel experiments

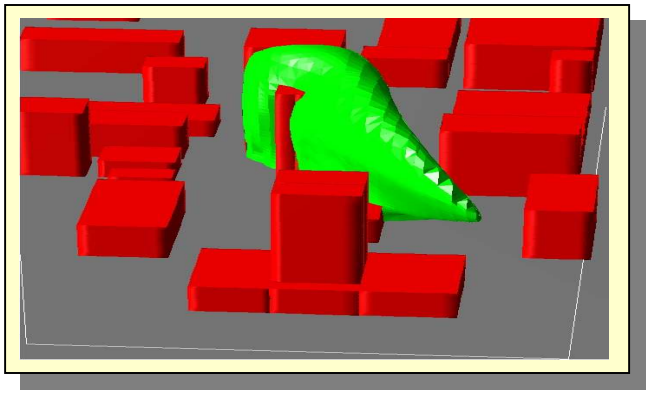
Downtown Oklahoma City



Wind Direction



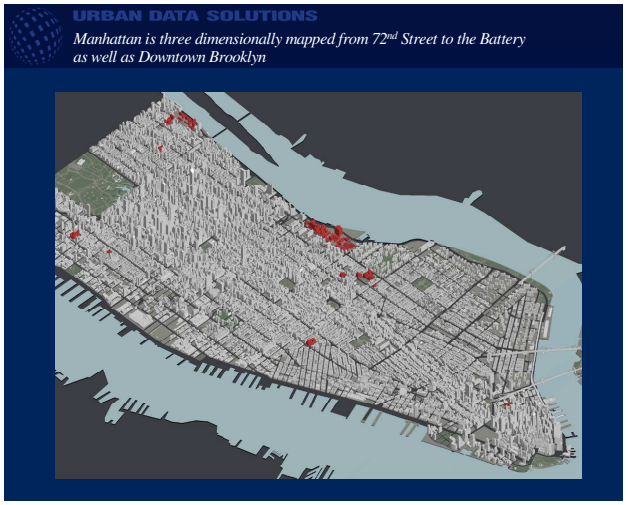
Release south of downtown (A)

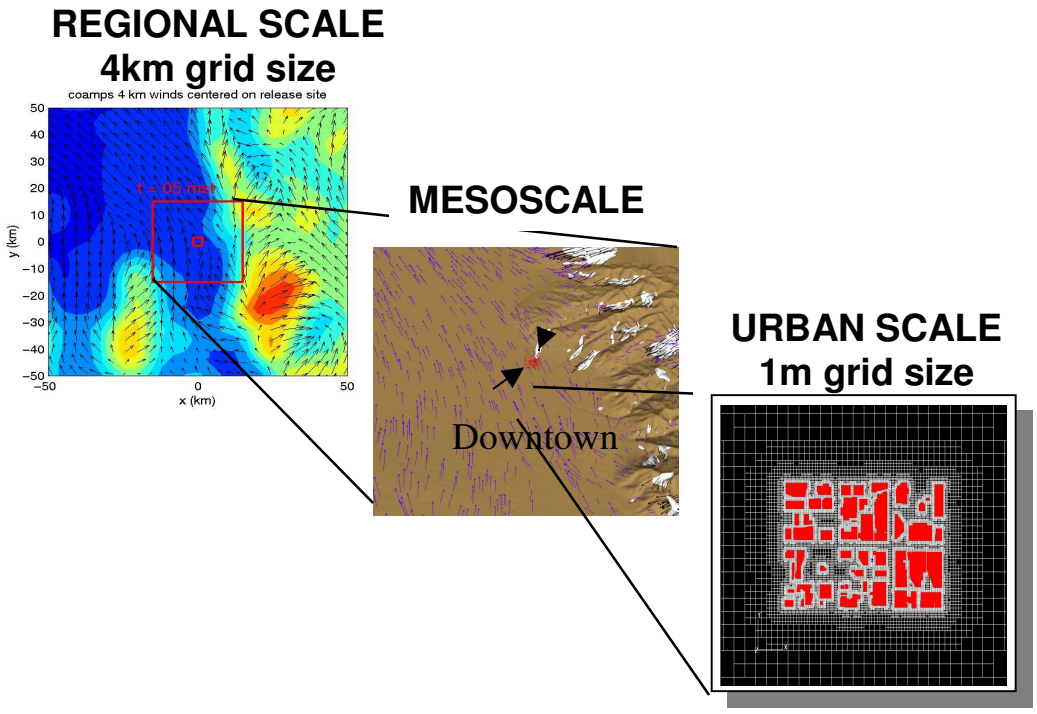


Release in downtown area (B)

Longer term research issues

- **Coupling models with different scales**
- **Integrate our external model with internal flow models (subways, arenas, etc.) – J. Shadid, SNL**





- **Large-scale cityscapes (e.g. Manhattan)**
- **Performance on diverse parallel architectures**

A next-generation airborne dispersion modeling capability

- We are pursuing a new urban dispersion modeling tool by combining technologies developed in CASC and NARAC
- Fast problem setup and adaptive gridding capabilities will make the tool a candidate for inclusion in NARAC's operational set of models
- Anticipate tool with primary features will be ready by late 2005